

US EPA ARCHIVE DOCUMENT



Real World Applications of Risk Assessment for Drinking Water Security

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Overview

- Motivation
- Characteristics of Water Distribution Systems
- The TEVA Research Program
- TEVA Risk Assessment Methodology
 - Predicting Exposure
 - Estimating Health Impacts
 - Incorporating Uncertainty
- Research Needs

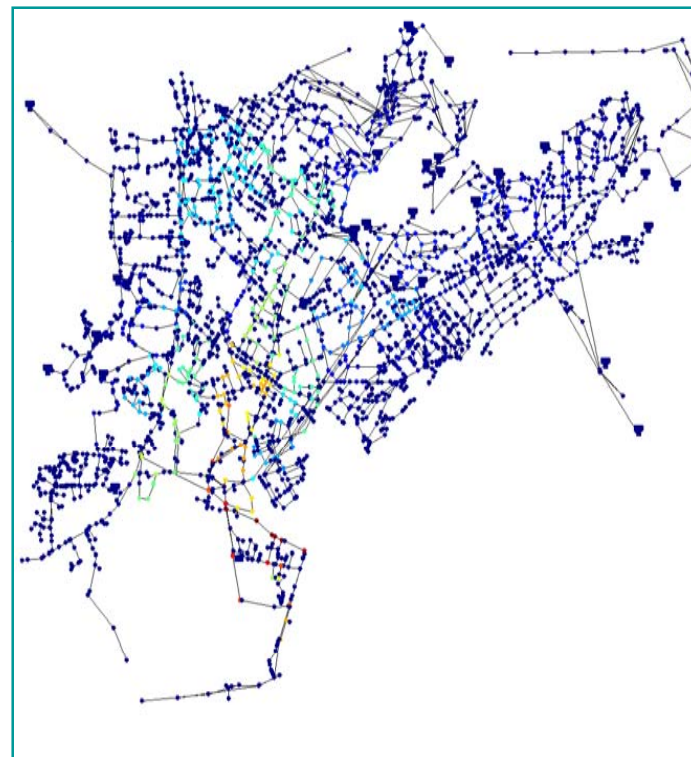


Motivation

- Quantitative risk assessment in water distribution systems can help answer many of the questions being asked by water security researchers:
 - What are the likely public health consequences of contamination events in drinking water?
 - What detection strategies will work and how effective are they?
 - What is the best system-specific design for a mitigation technology?
 - How does this approach compare to another strategy?

Characteristics of Water Distribution Systems

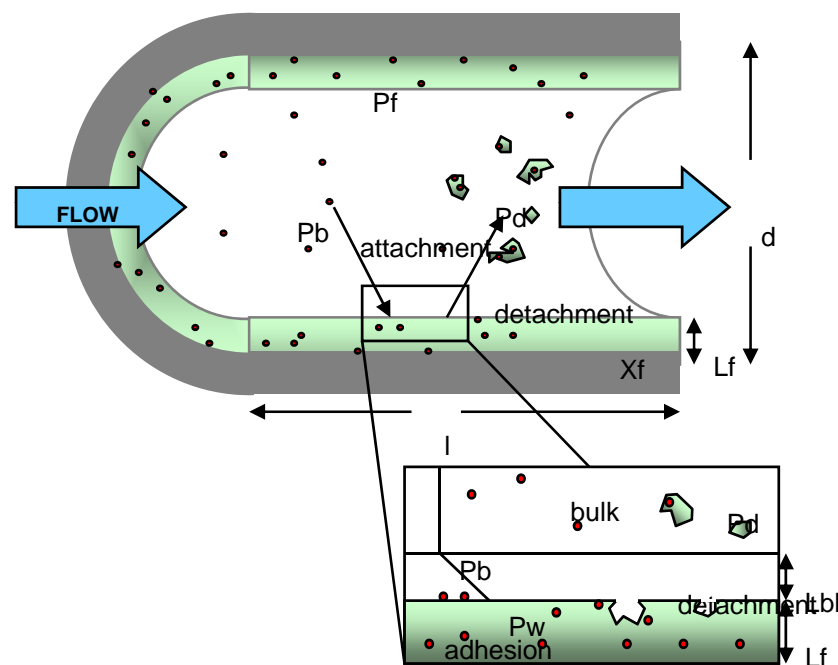
- **Topology**
 - Spatially distributed infrastructure over hundreds of miles
- **Flow patterns**
 - Looped
 - Multiple flow paths
 - Driven by customer demands
 - Subject to operational constraints



Characteristics of Water Distribution Systems

• Contaminant fate and transport

- Mixing at junctions
- Interaction with substances in the bulk water
 - Disinfectant residual
 - Natural organic matter
- Reaction with pipe walls
 - Adsorption/desorption to pipe materials and corrosion products
 - Attachment to biofilms





The TEVA Research Program

Research Team

- EPA/NHSRC/WIPD
- EPA/NRMRL/WSWRD
- University of Cincinnati
- Argonne National Laboratory
- Sandia National Laboratories

Partners

- American Water Works Association (AWWA)
- 9 Partner Utilities
- 22 Utilities

Objective

- To develop quantitative methods to assess risk and to evaluate risk mitigation strategies for drinking water distribution systems.



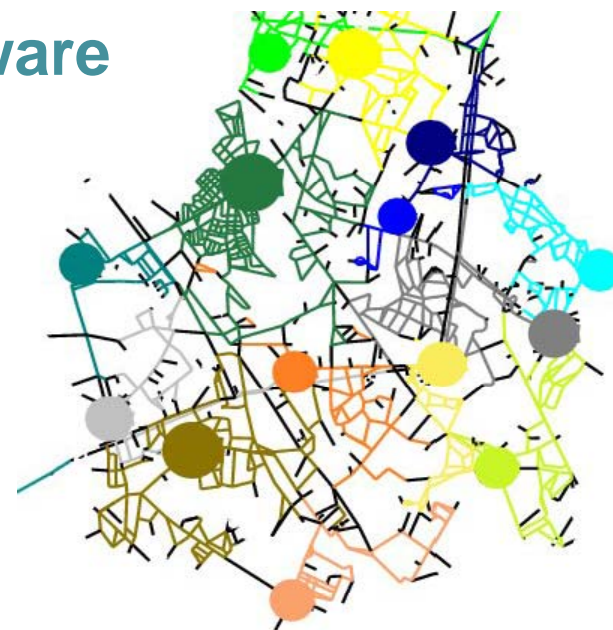
TEVA-SPOT Sensor Placement Software

How TEVA-SPOT works:

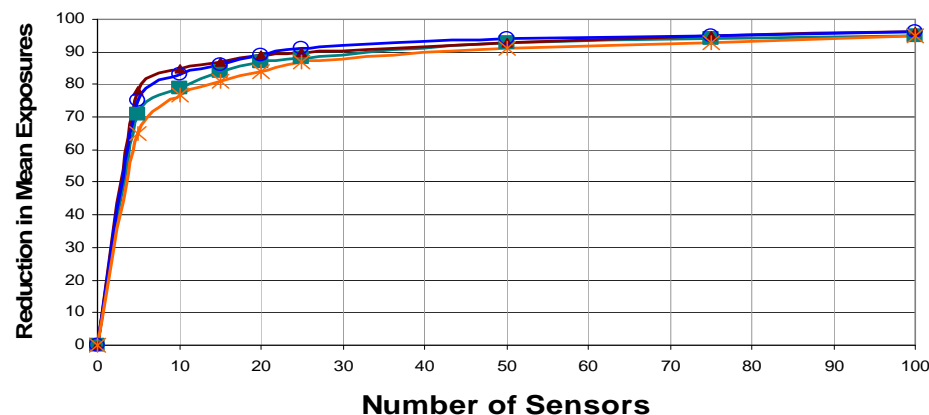
- User specifies design basis threat
- User provides network model
- Selects optimal design for sensor network throughout distribution system

TEVA-SPOT status:

- Tested on data from nine partner utilities
- Designs have been or will be implemented at several utilities
- Used to design sensor network for WSI pilot utility
- Will be available to public on EPA website



Sensor Cost/Benefit Curve





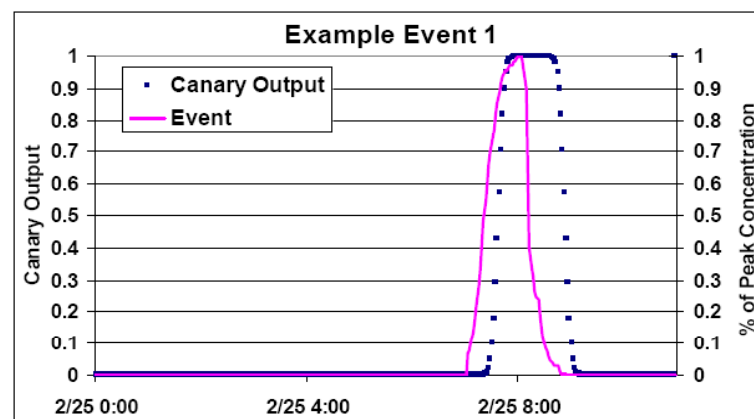
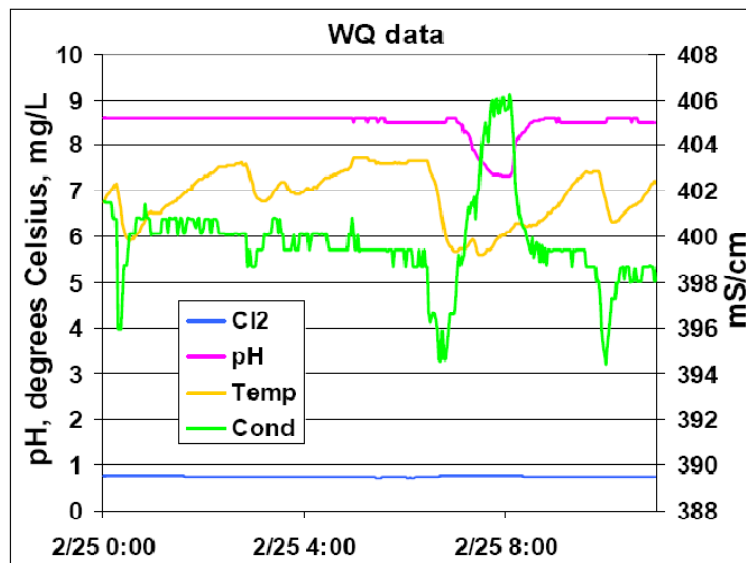
CANARY Event Detection Software

How CANARY works:

- Analyzes water quality in real-time
- Differentiates between background variability and anomalous events

CANARY status:

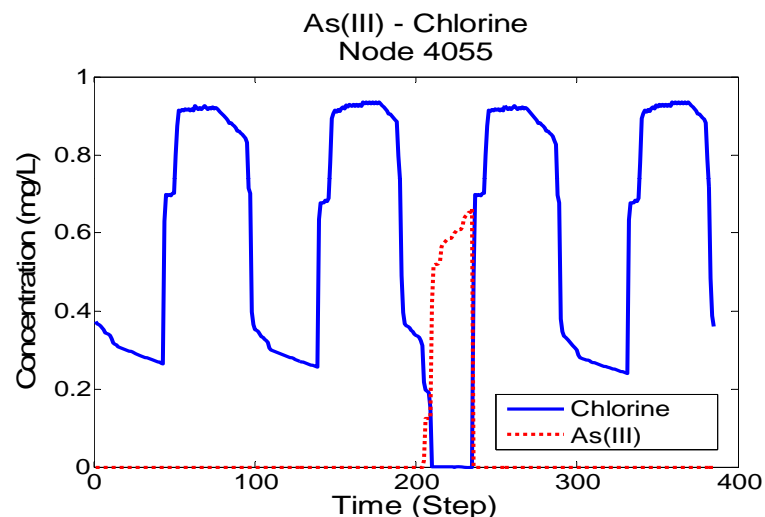
- Tested on data from two partner utilities
- Tested on data from T&E sensor experiments
- Operating at WSI pilot utility since July 2007
- Will be available to public on EPA website





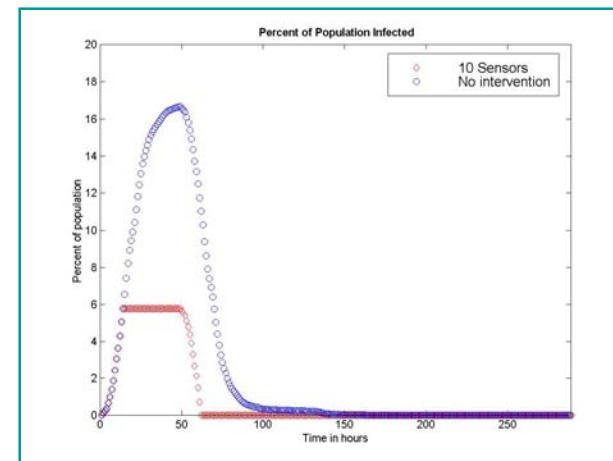
EPANET-MSX (Multi-Species eXtension)

- EPANET-MSX is an extension to EPANET that allows for the modeling of multiple interacting contaminants in drinking water pipe networks.
- EPANET-MSX is both a command-line executable, and an application programming interface (API), which is used in conjunction with the EPANET Toolkit
- Software and User's Manual available on EPANET website





TEVA Risk Assessment Methodology



- Quantitative risk assessment underlies the TEVA software tools
- Public health impacts and economic impacts are calculated in order to measure the reduction in impacts (or benefits) of mitigation technologies
- Extensions to modeling tools are needed for accurate risk assessments



TEVA methodology to estimate public health impacts from consumption of contaminated water

Hydraulic Model

EPANET predicts

- Velocity, $V(x,t)$
- Pressure, $P(x,t)$
- Concentration, $B(x,t)$

Disease Transmission Model

Applied at each node

- Susceptible, $S(x_n,t)$
- Infected, $I(x_n,t)$
- Diseased, $D(x_n,t)$
- Fatalities, $F(x_n,t)$

Exposure Model

Concentration $B(x,t)$ → Dose $D(x,t)$ → Response $R(x,t)$ → Infectivity Rate $\lambda(x,t)$



Hydraulic Model

Hydraulic Model

EPANET predicts

- Velocity, $V(x,t)$
- Pressure, $P(x,t)$
- Concentration, $B(x,t)$

- Configured for each water utility
- Reflects operational and user demand patterns
- EPANET
- EPANET-MSX



Office of Research and Development
National Homeland Security Research Center



Exposure Model

Exposure Model

Concentration $B(x,t)$ \longrightarrow Dose $D(x,t)$ \longrightarrow Response $R(x,t)$ \longrightarrow Infectivity Rate λ

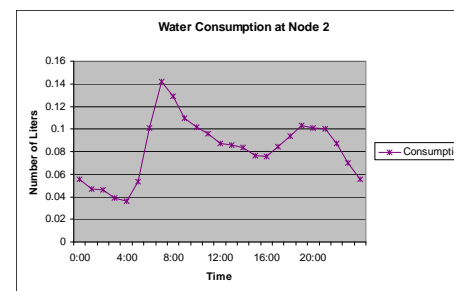
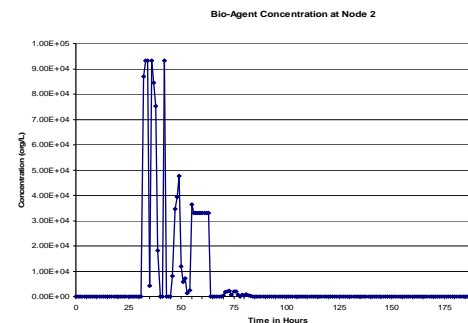
The dose received by an individual is the summed product of the contaminant concentration and the water consumed:

$$\text{Dose}(x_n) = \sum_i \{B(x_n, t_i) \times W_c(x_n, t_i)\} \text{ where}$$

$B(x_n, t_i)$ = Concentration of Cont.

$W_c(x_n, t_i)$ = Water Consumed

$$= (1/12) \times D(x_n, t_i) / \text{Avg}\{D(x_n, t_i)\}$$





Dynamic Disease Transmission Model

Disease Transmission Model

Applied at each node

- Susceptible, $S(x_n, t)$
- Infected, $I(x_n, t)$
- Diseased, $D(x_n, t)$
- Fatalities, $F(x_n, t)$

$$\frac{dS}{dt} = \gamma R(t) - (\lambda(B, t) + \mu)S(t) \quad (1)$$

$$\frac{dI}{dt} = \lambda(B, t)S(t) - (\sigma + \mu)I(t) \quad (2)$$

$$\frac{dD}{dt} = \sigma I(t) - (\alpha + \mu + v)D(t) \quad (3)$$

$$\frac{dR}{dt} = vD(t) - (\mu + \gamma)R(t) \quad (4)$$

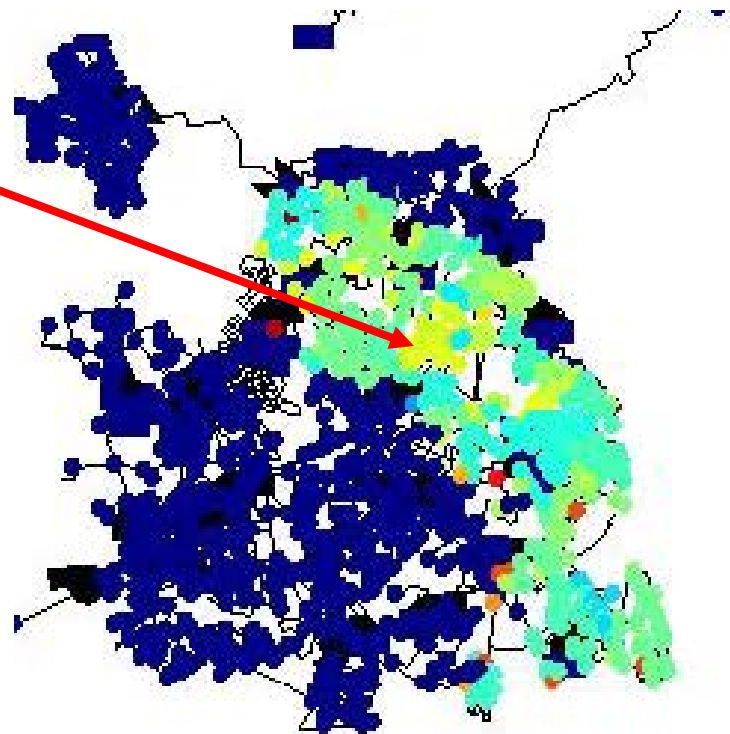
$$\frac{dF}{dt} = \alpha D(t) \quad (5)$$

where $S(t)$ is the number of susceptible persons at time t , $I(t)$ the number of infected, $D(t)$ the number of diseased (infected and symptomatic), $R(t)$ the number of recovered and immune, $F(t)$ the number of fatalities due to disease, and $B(t)$ the population of organisms.



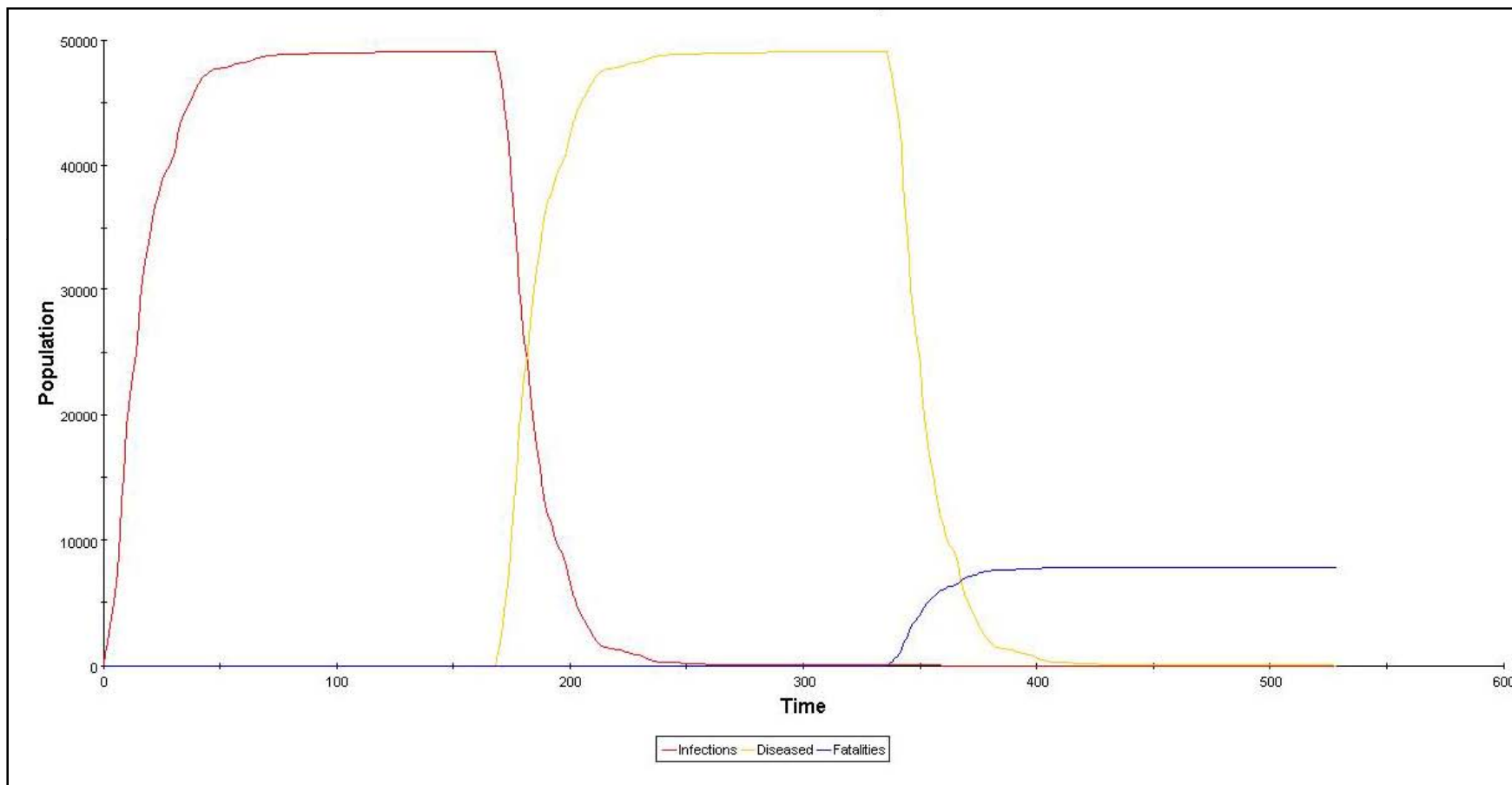
Network-wide Consequences

Attack Site



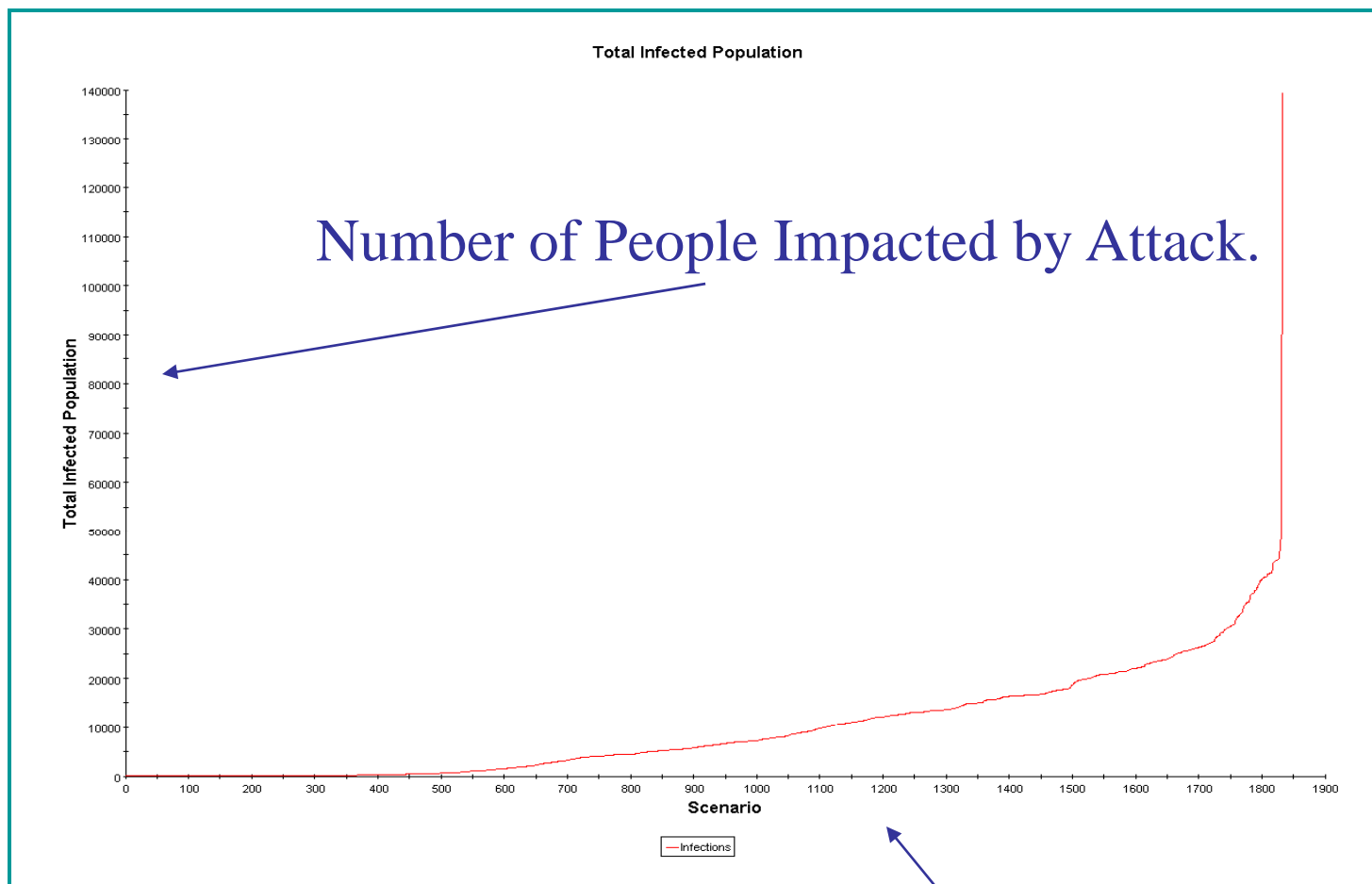


Network-wide Population Infected, Symptomatic, and Fatally Impacted Over Time





Total Impact Statistics Over Many Scenarios: Effect of varying Location





Uncertainty

- Not enough data to deterministically predict:
 - **Contamination scenarios:**
 - Attack location
 - Time of day and length of attack
 - Type of contaminant
 - Amount and concentration of contaminant
 - **Customer behavior:**
 - Timing and amount of water consumed
 - Movement through the spatial network (work, home, school, etc.)



Research Needs

- Contaminant fate and transport in drinking water
 - Disinfection reactions
 - Adsorption/desorption mechanics
 - Attachment to biofilms
- Incorporation of uncertainty into models
 - Monte Carlo extension to EPANET
- Improved exposure models
 - Variability in population risk
 - Realistic customer behavior



THANK YOU!

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